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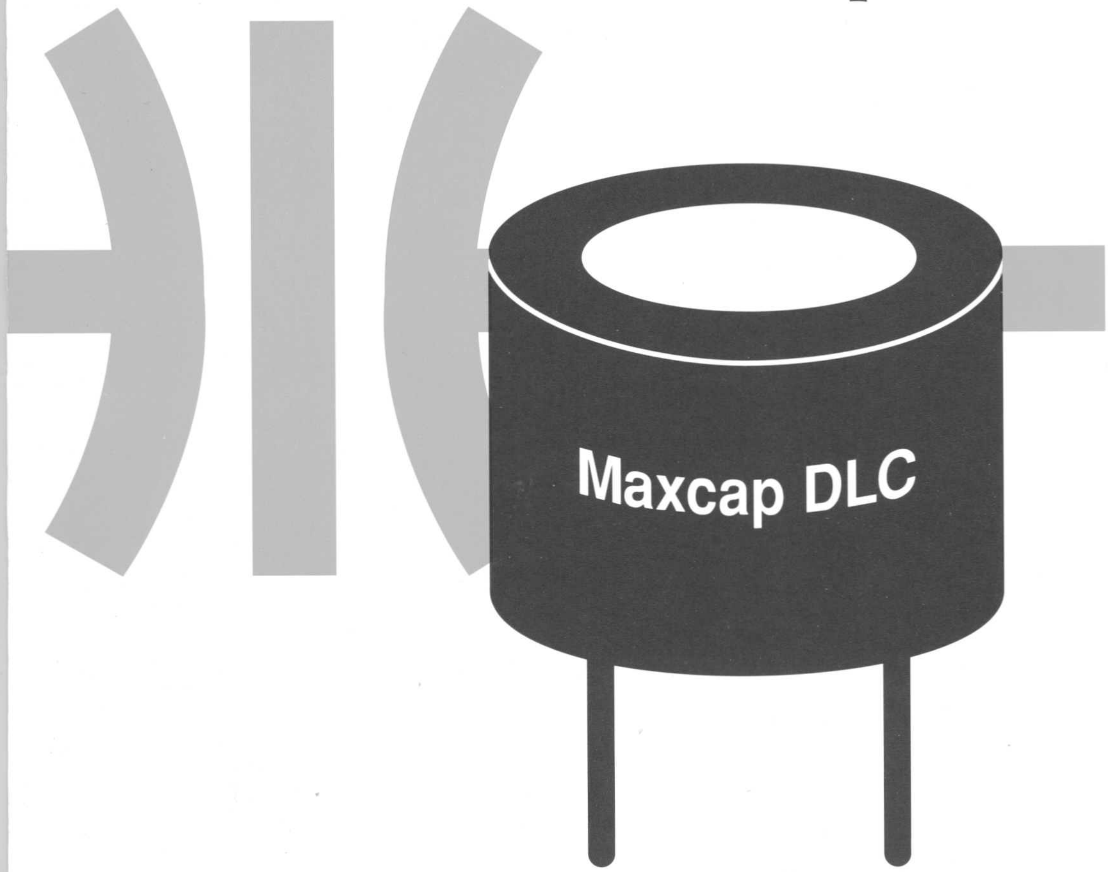
Maxcap®
Double Layer Capacitors



Product Information and Application Data

Maxcap® Double Layer Capacitors

Product Information and Application Data

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Maxcap® Double Layer Capacitors

High Energy Density Capacitors for Memory Backup Power

One Farad in a 0.85" x 0.63" Package

Up to 2.2 Farads in a Single 5.5 Volt Package

Up to 1.0 Farad in a Single 11.0 Volt Package

Maxcap® double layer capacitors are a new electric energy storage device with extremely high volumetric efficiency (over three farads/in³), virtually unlimited service life, fast charge/discharge capability and very low leakage current.

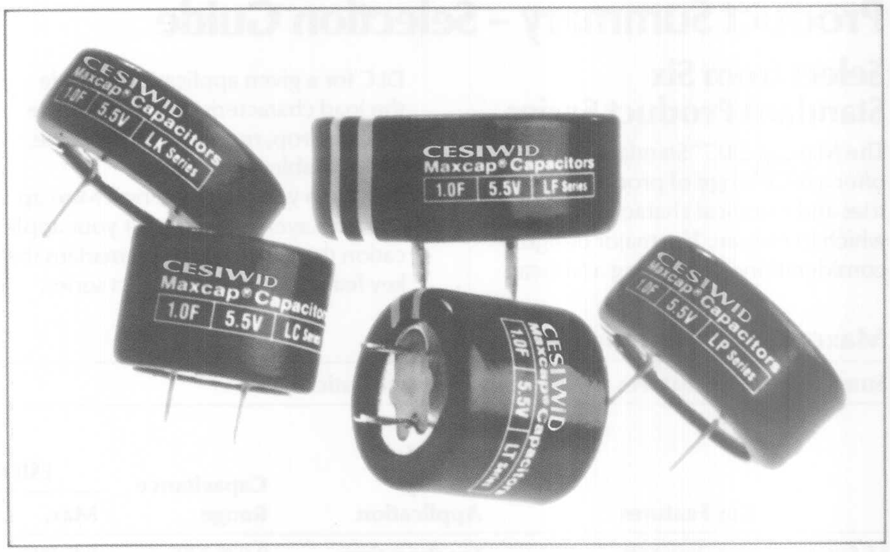
Pioneered by Sohio and The Carborundum Company, the Maxcap DLC Product Line was purchased by Cesiwid in 1993.

A Maxcap DLC the size of a thimble will support microamp data retention currents of CMOS RAMs for up to several weeks. Microprocessors, small motors and activators having current requirements from one to several hundred milliamps can be supported from several seconds to minutes.

Conventional energy storage devices such as batteries and aluminum electrolytic capacitors often must be replaced during the life of a product. Maxcap DLCs never need replacing because, unlike batteries, they do not undergo life-limiting, irreversible, chemical reactions, and, unlike aluminum electrolytic capacitors, they do not experience dry-up problems.

The high capacitance of Maxcap DLCs results from an electric double layer formed at the interface of high surface area activated carbon and a stable electrolyte. Unit cells are formed by separating two carbon/electrolyte wafers with an ionically conductive porous separator and sandwiching them between two electrically conductive, ionically impermeable membranes. The unit cells are stacked in series to achieve the desired capacitor voltage.

CAUTION: Due to their relatively high internal resistance, Maxcap DLCs should not be subjected to large ripple currents.



Key Features

- **Very high capacity in small size.** Up to 100 times that of conventional capacitors. Circuit board space and equipment size can be reduced.
- **Useful voltage ratings:** 5.5 volt – Ideal for CMOS operating voltage range. 11 volt – LV Series, backup for relays, actuators, small motors.
- **Full range of sizes.** From 0.022 to 2.2 farads @5.5 volts; 0.47 and 1.0 farads @11 volts.
- **Low profile** with LP and LK Series
- **Ultra long life.** Unlike batteries, Maxcap DLCs have no parasitic chemical reactions. They can be fully charged and discharged indefinitely. There is no "memory" effect.
- **Maintenance free.** Maxcap DLCs can be placed in remote locations and require no access ports. Warranty claims are minimized.
- **Nonpolar.** Assembly errors and costs are minimized.
- **Wide operating temperature range:** -40 to +85°C LT Series; -25 to +70°C LP, LC, LK, LF Series
- **Simple, low cost circuitry.** Since Maxcap DLCs do not require current limiting resistors or over-voltage protection, component costs and assembly time are reduced.
- **Safer than batteries.** These capacitors will not explode or be damaged if short circuited. They can be installed with wave soldering equipment.

Applications

Typical Maxcap DLC Backup Power Applications

Type of Load	Appliance or Equipment
CMOS, RAMS and Microprocessors, Timers for Integrated Circuits	Home appliances such as TVs, microwave ovens, dishwashers, and refrigerators; telephone autodialers, personal computers, energy management controls, thermostats, point of sale terminals, programmable controllers
Relays, Solenoids	Starters, igniters, actuators
Small Motors, Alarms	Disc drives, coin metering devices, security systems, toys

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Product Summary – Selection Guide

Select from Six Standard Product Series

The Maxcap DLC "Standard Products" offer a wide range of product geometries and electrical characteristics from which to choose. The major design considerations in selecting a Maxcap DLC for a given application include the load characteristic, the allowable voltage drop, required backup time, and available board space.

To help you select the best Maxcap Double Layer Capacitor for your application the table below summarizes the key features of each product series.

Maxcap DLC Standard Products

Summary of Key Features and Electrical Characteristics

	Key Features	Typical Backup Application	Capacitance Range	ESR Range Max.	ESR Range Typical	Typical* Long Charge Leakage Current	Operating Temperature
LF Series (5.5 Volt)	Very low ESR	For short time, high current (up to amps)	0.047-1.5F	0.6-14Ω	0.2-7Ω	1-25 μa	-25 to +70°C
LP Series (5.5 Volt)	Low height, low ESR	Days to week (up to milliamps)	0.022-1.0F	7-60Ω	1-20Ω	1-25 μa	-25 to +70°C
LC Series (5.5 Volt)	Reduced diameter, high energy density, low leakage current	Several weeks (microamps)	0.022-2.2F	35-220Ω	5-80Ω	0.1-6 μa	-25 to +70°C
LK Series (5.5 Volt)	Reduced height, high energy density, low leakage current	Several weeks (microamps)	0.022-1.0F	20-200Ω	2-120Ω	0.1-4 μa	-25 to +70°C
LT Series (5.5 Volt)	Expanded temperature range, low leakage current	Several weeks (microamps)	0.022-1.0F	60-220Ω	5-120Ω	0.1-4 μa	-40 to +85°C
LV Series (11 Volt)	Increased voltage capability, low ESR	For short time, high current, high voltage (up to milliamps)	0.47 & 1.0F	7Ω	1.5-5Ω	1-4 μa	-25 to +70°C

*Charging current after 72 hours with 1000Ω resistor in series with capacitor at 25°C

Ordering Information

Model Numbering System

LP	055	104	A
Maxcap DLC Product Series	Maximum Working Voltage 055 = 5.5VDC	Capacitance in μF. First two digits are significant figures, third digit is number of zeros to follow e.g., 104 = 100,000	Capacitance Tolerance +80% −20%

Epoxy End Seal Option: An epoxy end seal can be specified by adding "E" to the part number, e.g., LP055104AE. Capacitors with epoxy end seals are non-standard products.

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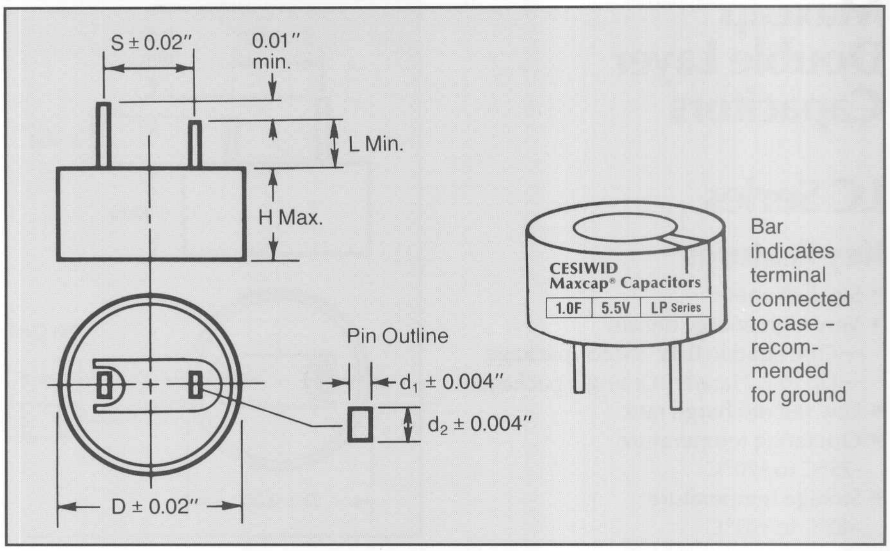
Maxcap Double Layer Capacitors

LP Series

Key Features

- Low profile, low ESR
- One farad in 1.1″ x 0.6″ package
- Operating temperature -25°C to +70°C
- Storage temperature -40°C to +85°C



Maxcap DLC Standard Products

Electrical Characteristics

Part No.	Capacitance Farads	Maximum Working Voltage Volts, D.C.	Surge Voltage Volts, D.C.	Maximum ESR Ohms @ 1 kHz	Typical ESR Ohms @ 1 kHz	Maximum Charging Current After 30 Minutes Milliamps	Weight Grams, Typical
LP055223A	0.022	5.5	6.3	60	10-20	0.033	1.6
LP055473A	0.047	5.5	6.3	40	7-14	0.071	2.6
LP055104A	0.1	5.5	6.3	25	4-10	0.15	4.1
LP055224A	0.22	5.5	6.3	25	5-10	0.33	5.3
LP055474A	0.47	5.5	6.3	13	2-5	0.71	10
LP055105A	1.0	5.5	6.3	7	1-3	1.50	18

Dimensions - inches (mm)

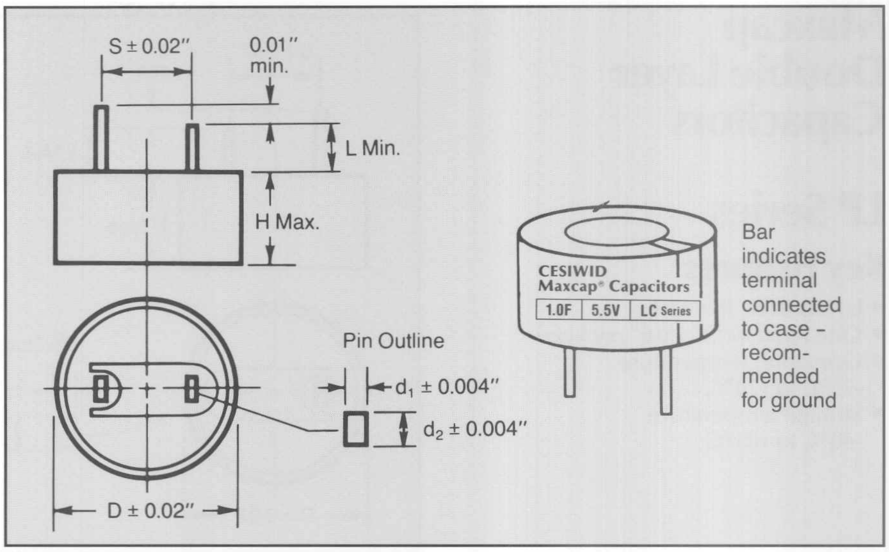
Part No.	Capacitance Farads	Diameter D	Maximum Height H Max.	Pin Spacing S	Pin Outline $d_1 \times d_2$	Pin Length L Min.
LP055223A	0.022	0.45 (11.5)	0.34 (8.5)	0.2 (5.1)	0.016 x 0.048 (0.4 x 1.2)	0.106 (2.7)
LP055473A	0.047	0.50 (12.5)	0.34 (8.5)	0.2 (5.1)	0.016 x 0.048 (0.4 x 1.2)	0.087 (2.2)
LP055104A	0.1	0.63 (16.0)	0.34 (8.5)	0.2 (5.1)	0.016 x 0.048 (0.4 x 1.2)	0.106 (2.7)
LP055224A	0.22	0.63 (16.0)	0.51 (13.0)	0.2 (5.1)	0.016 x 0.048 (0.4 x 1.2)	0.106 (2.7)
LP055474A	0.47	0.83 (21.0)	0.51 (13.0)	0.3 (7.6)	0.024 x 0.048 (0.6 x 1.2)	0.118 (3.0)
LP055105A	1.0	1.12 (28.5)	0.55 (14.0)	0.4 (10.2)	0.024 x 0.055 (0.6 x 1.2)	0.240 (6.1)

Maxcap Double Layer Capacitors

LC Series

Key Features

- Small diameter
- Very high energy density
  —One farad in 0.85" x 0.63" package
  —Up to 2.2 farads in a single package
- Low self discharge rate
- Operating temperature
  -25°C to +70°C
- Storage temperature
  -40°C to +85°C



Maxcap DLC Standard Products

Electrical Characteristics

Part No.	Capacitance Farads	Maximum Working Voltage Volts, D.C.	Surge Voltage Volts, D.C.	Maximum ESR Ohms @ 1 kHz	Typical ESR Ohms @ 1 kHz	Maximum Charging Current After 30 Minutes Milliamps	Weight Grams, Typical
LC055223A	0.022	5.5	6.3	220	40-80	0.033	1.6
LC055473A	0.047	5.5	6.3	220	40-80	0.071	1.7
LC055104A	0.10	5.5	6.3	100	20-40	0.15	2.4
LC055224A	0.22	5.5	6.3	120	20-50	0.33	4.3
LC055474A	0.47	5.5	6.3	65	10-25	0.71	6.0
LC055105A	1.0	5.5	6.3	35	5-15	1.5	11.0
LC055145A	1.4	5.5	6.3	45	5-20	2.1	12.1
LC055225A	2.2	5.5	6.3	35	5-15	3.3	23.1

Dimensions – inches (mm)

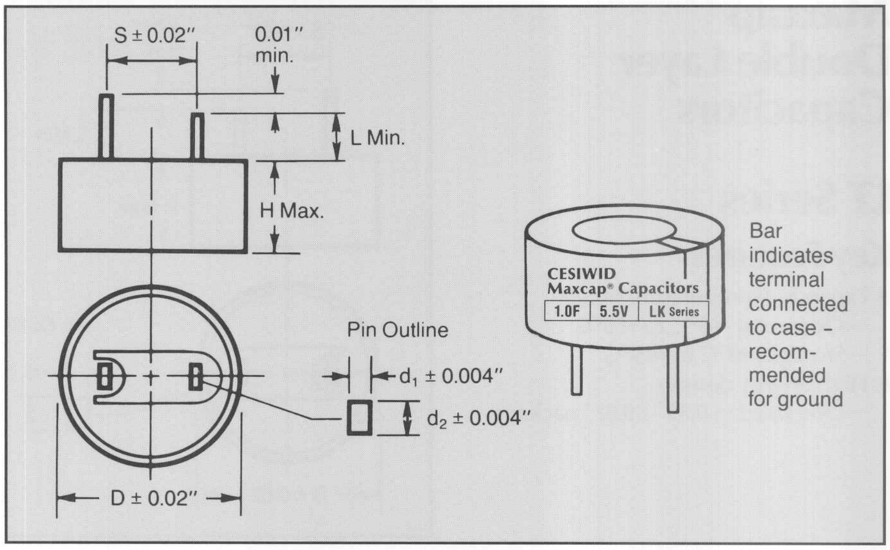
Part No.	Capacitance Farads	Diameter D	Maximum Height H Max.	Pin Spacing S	Pin Outline d_1 x d_2	Pin Length L Min.
LC055223A	0.022	0.45 (11.5)	0.34 (8.5)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LC055473A	0.047	0.45 (11.5)	0.34 (8.5)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LC055104A	0.1	0.51 (13.0)	0.34 (8.5)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.087 (2.2)
LC055224A	0.22	0.57 (14.5)	0.59 (15.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.095 (2.4)
LC055474A	0.47	0.65 (16.5)	0.59 (15.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LC055105A	1.0	0.85 (21.5)	0.63 (16.0)	0.3 (7.6)	0.024 x 0.047 (0.6 x 1.2)	0.118 (3.0)
LC055145A	1.4	0.85 (21.5)	0.75 (19.0)	0.3 (7.6)	0.024 x 0.047 (0.6 x 1.2)	0.118 (3.0)
LC055225A	2.2	1.12 (28.5)	0.87 (22.1)	0.4 (10.2)	0.024 x 0.055 (0.6 x 1.4)	0.240 (6.1)

Maxcap Double Layer Capacitors

LK Series

Key Features

- Low profile
- Very high energy density
  —One farad in 1.12″ x 0.43″ package
- Low self discharge rate
- Operating temperature
  -25°C to +70°C
- Storage temperature
  -40°C to +85°C



Maxcap DLC Standard Products

Electrical Characteristics

Part No.	Capacitance Farads	Maximum Working Voltage Volts, D.C.	Surge Voltage Volts, D.C.	Maximum ESR Ohms @ 1 kHz	Typical ESR Ohms @ 1 kHz	Maximum Charging Current After 30 Minutes Milliamps	Weight Grams, Typical
LK055223A	0.022	5.5	6.3	200	80-120	0.033	1.5
LK055473A	0.047	5.5	6.3	100	20-40	0.071	2.1
LK055104A	0.1	5.5	6.3	50	10-25	0.15	3.3
LK055224A	0.22	5.5	6.3	60	10-25	0.33	3.7
LK055474A	0.47	5.5	6.3	35	5-15	0.71	7.1
LK055105A	1.0	5.5	6.3	20	2-7	1.5	13.7

Dimensions – inches (mm)

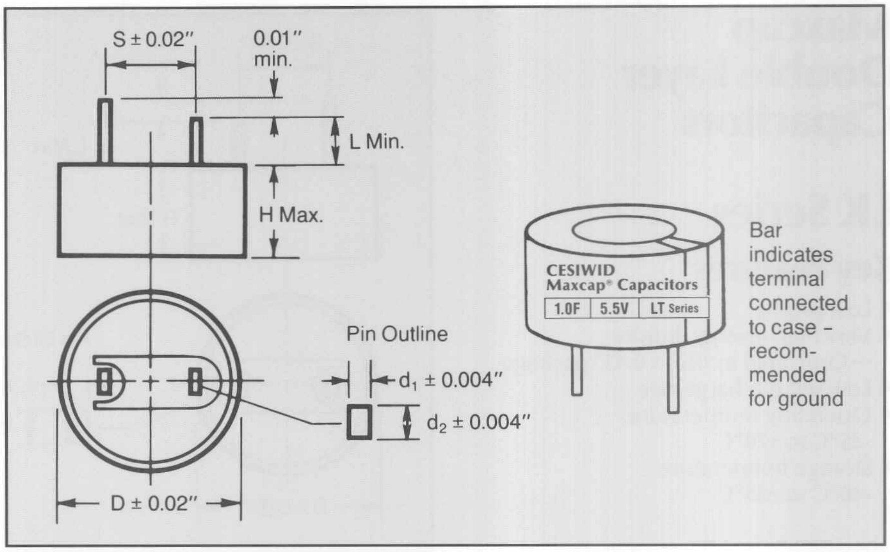
Part No.	Capacitance Farads	Diameter D	Maximum Height H Max.	Pin Spacing S	Pin Outline $d_1 \times d_2$	Pin Length L Min.
LK055223A	0.022	0.45 (11.5)	0.28 (7.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LK055473A	0.047	0.51 (13.0)	0.28 (7.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.087 (2.2)
LK055104A	0.1	0.65 (16.5)	0.30 (7.5)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LK055224A	0.22	0.65 (16.5)	0.38 (9.5)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LK055474A	0.47	0.85 (21.5)	0.40 (10.0)	0.3 (7.6)	0.024 x 0.047 (0.6 x 1.2)	0.118 (3.0)
LK055105A	1.0	1.12 (28.5)	0.44 (11.0)	0.4 (10.2)	0.024 x 0.055 (0.6 x 1.4)	0.240 (6.1)

Maxcap Double Layer Capacitors

LT Series

Key Features

- Expanded temperature range
  —Operating -40°C to +85°C
  —Storage -40°C to +85°C
- High energy density
  —One farad in 0.85″ x 0.87″ package



Maxcap DLC Standard Products

Electrical Characteristics

Part No.	Capacitance Farads	Maximum Working Voltage Volts, D.C.	Surge Voltage Volts, D.C.	Maximum ESR Ohms @ 1 kHz	Typical ESR Ohms @ 1 kHz	Maximum Charging Current After 30 Minutes Milliamps	Weight Grams, Typical
LT055223A	0.022	5.5	6.3	220	80-120	0.033	2.3
LT055473A	0.047	5.5	6.3	110	20-50	0.071	3.9
LT055104A	0.10	5.5	6.3	150	20-50	0.15	4.3
LT055224A	0.22	5.5	6.3	180	25-60	0.33	5.3
LT055474A	0.47	5.5	6.3	100	10-25	0.71	7.5
LT055105A	1.0	5.5	6.3	60	5-15	1.50	13.3

Dimensions – inches (mm)

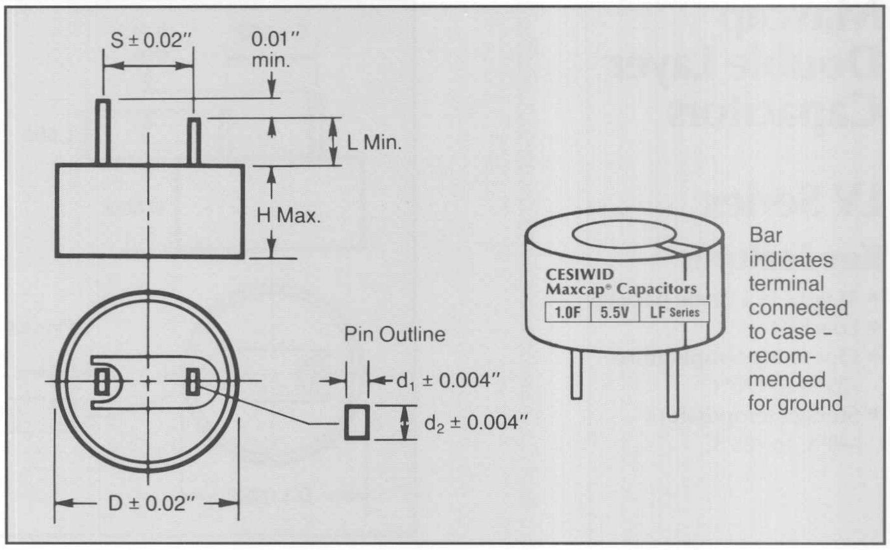
Part No.	Capacitance Farads	Diameter D	Maximum Height H Max.	Pin Spacing S	Pin Outline d_1 x d_2	Pin Length L Min.
LT055223A	0.022	0.45 (11.5)	0.55 (14.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LT055473A	0.047	0.57 (14.5)	0.55 (14.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.095 (2.4)
LT055104A	0.10	0.57 (14.5)	0.61 (15.5)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.095 (2.4)
LT055224A	0.22	0.57 (14.5)	0.83 (21.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.095 (2.4)
LT055474A	0.47	0.65 (16.5)	0.85 (21.5)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LT055105A	1.0	0.85 (21.5)	0.87 (22.0)	0.3 (7.6)	0.016 x 0.047 (0.4 x 1.2)	0.118 (3.0)

Maxcap Double Layer Capacitors

LF Series

Key Features

- Very low ESR
  —As low as 0.3Ω, typical
- High energy density
  —One farad in 1.44″ x 0.73″ package
  —Up to 1.5 farads in single package
- Operating temperature
  -25°C to +70°C
- Storage temperature
  -40°C to +85°C



Maxcap DLC Standard Products

Electrical Characteristics

Part No.	Capacitance Farads	Maximum Working Voltage Volts, D.C.	Surge Voltage Volts, D.C.	Maximum ESR Ohms @ 1 kHz	Typical ESR Ohms @ 1 kHz	Maximum Charging Current After 30 Minutes Milliamps	Weight Grams, Typical
LF055473A	0.047	5.5	6.3	14	4-7	0.071	3.8
LF055104A	0.1	5.5	6.3	6.5	2-4	0.15	4.8
LF055224A	0.22	5.5	6.3	3.5	1-3	0.33	9.7
LF055474A	0.47	5.5	6.3	1.8	0.5-1.0	0.71	16
LF055105A	1.0	5.5	6.3	1.0	0.3-0.6	1.5	38
LF055155A	1.5	5.5	6.3	0.6	0.2-0.4	2.3	72

Dimensions - inches (mm)

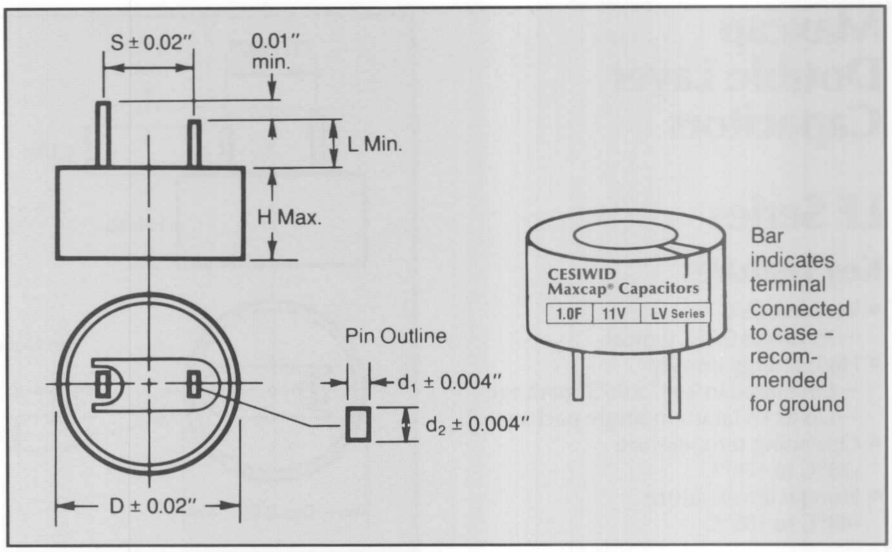
Part No.	Capacitance Farads	Diameter D	Maximum Height H Max.	Pin Spacing S	Pin Outline $d_1 \times d_2$	Pin Length L Min.
LF055473A	0.047	0.57 (14.5)	0.55 (14.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.087 (2.2)
LF055104A	0.1	0.65 (16.5)	0.55 (14.0)	0.2 (5.1)	0.016 x 0.047 (0.4 x 1.2)	0.106 (2.7)
LF055224A	0.22	0.85 (21.5)	0.61 (15.5)	0.3 (7.6)	0.024 x 0.047 (0.6 x 1.2)	0.118 (3.0)
LF055474A	0.47	1.12 (28.5)	0.65 (16.5)	0.4 (10.2)	0.024 x 0.055 (0.6 x 1.4)	0.240 (6.1)
LF055105A	1.0	1.44 (36.5)	0.73 (18.5)	0.59 (15.0)	0.024 x 0.067 (0.6 x 1.7)	0.240 (6.1)
LF055155A	1.5	1.75 (44.5)	0.73 (18.5)	0.79 (20.0)	0.039 x 0.055 (1.0 x 1.4)	0.240 (6.1)

Maxcap Double Layer Capacitors

LV Series

Key Features

- 11 volts in a single package
- Low ESR
- Operating temperature -25°C to +70°C
- Storage temperature -40°C to +85°C



Maxcap DLC Standard Products

Electrical Characteristics — **Weight**

Part No.	Capacitance Farads	Maximum Working Voltage Volts, D.C.	Surge Voltage Volts, D.C.	Maximum ESR Ohms @ 1 kHz	Typical ESR Ohms @ 1 kHz	Maximum Charging Current After 30 Minutes Milliamps	Grams, Typical
LV110474A	0.47	11.0	12.6	7	2-5	1.41	10
LV110105A	1.0	11.0	12.6	7	1-3	3.0	18

Dimensions - inches (mm)

Part No.	Capacitance Farads	Diameter D	Maximum Height H Max.	Pin Spacing S	Pin Outline $d_1 \times d_2$	Pin Length L Min.
LV110474A	0.47	1.12 (28.5)	1.00 (25.5)	0.4 (10.2)	0.024 x 0.055 (0.6 x 1.4)	0.240 (6.1)
LV110105A	1.0	1.12 (28.5)	1.24 (31.5)	0.4 (10.2)	0.024 x 0.055 (0.6 x 1.4)	0.240 (6.1)

Maxcap DLC Specifications

Item	Test	Specifications	Capacitance	ESR
1. Capacitance	See test method, page 12.	*		
2. Capacitance Tolerance	—	+80%, -20%		
3. DC Maximum Working Voltage	—	5.5 VDC & 11.0 VDC		
4. Surge Voltage	Capacitors cycled from 0 → rated surge voltage → 0 volts 1000 times at max. operating temperature	6.3 VDC & 12.6 VDC	≥90%**	≤120%**
5. Equivalent Series Resistance (ESR)	See test method, page 12.	*		
6. Maximum Charging Current	See test method, page 12.	*		
7. Operating Temperature	See items 11, 12, and 13 below.	LC, LF, LK, LP, LV Series: -25°C to +70°C LT Series: -40°C to +85°C		
8. Storage Temperature	See item 14 below	-40°C to +85°C		
9. Lead Strength	Pull test, 1 kg for 60 seconds	No breaks		
10. Solderability	Soldering temperature 230°C ± 5°C for 5 ± 0.5 seconds	Shall cover more than 75% of lead surface		
11. Thermal Stability	LC, LF, LK, LP, LV Series: Capacitors cycled from +25°C(1) → -25°C(2) → +25°C(3) → +70°C(4) → +25°C(5)	Step 1 (+25°C) Step 2 (-25°C) Step 3 (+25°C) Step 4 (+70°C) Step 5 (+25°C)	* ≥50%*** ±20%*** ≤+150%*** ±20%***	* ≤+300%*** * * *
	LT Series: Capacitors cycled from +25°C(1) → -40°C(2) → +25°C(3) → +85°C(4) → +25°C	Step 1 (+25°C) Step 2 (-40°C) Step 3 (+25°C) Step 4 (+85°C) Step 5 (+25°C)	* ≥50%*** ±20%*** ≤+150%*** ±20%***	* ≤+300%*** * * *
12. Thermal Shock	Capacitors cycled 5 times with 30 minute exposure at each temperature with no voltage applied: LC, LF, LK, LP, LV Series: +25°C → -40°C → +25°C → +70°C → +25°C		*	*
	LT Series: +25°C → -40°C → +25°C → +85°C → +25°C		*	*
13. Life	Capacitors at rated temperature and voltage for 1000 hours: LC, LF, LK, LP, LV Series: Test temperature 70°C		≥70%***	≤+200%**
	LT Series: Test temperature 85°C		≥70%	≤+200%**
14. Storage Life	Capacitors at -40°C and +85°C for 500 hours each with no voltage applied		≥70%***	≥+200%**
15. Humidity	Capacitors at 90 to 95% relative humidity at 40°C for 500 hours with no voltage applied		*	*
16. Resistance to Soldering Heat	Soldering temperature at 260°C ± 10°C for 10 ± 1 seconds		*	*
17. Vibration	Frequency 10-55 cycles/sec., 1.5 mm amplitude, 3 directions 2 hours each (total 6 hours)		*	*

*See "Standard Product" tables. ** % of values in "Standard Product" tables *** % of initial measured value

Note: Typical failure rate of Maxcap DLCs is less than a 0.001%/1000 hours (less than 10 FIT) when tested at 25°C at rate voltage for 5000 hours.

Electrical Characteristic Measurement Methods

1. Capacitance

Capacitance in farads can be calculated by using the formula and charging test circuit in Figure 1:

a. Test temperature and tolerance – Capacitors to be at +25° ± 5°C.
b. Initial capacitor voltage to be less than 0.05V.
c. V_c = Volt meter (DC).
d. E_o = 5.0 ± 0.1V for LC, LF, LK, LP, LT Series; 10.0 ± 0.1V for LV Series.
e. T = Charging time constant, that is, the time period in seconds from 0 to reach 0.632 x E_o volts.
f. R_c = Charging resistor selected from the table below:

	LP Series	LC Series	LK Series	LT Series	LF Series	LV Series
0.022F	1kΩ	2kΩ	2kΩ	2kΩ	1kΩ	—
0.047F	1kΩ	2kΩ	1kΩ	1kΩ	1kΩ	—
0.1F	510Ω	510Ω	1kΩ	1kΩ	510Ω	—
0.22F	200Ω	510Ω	510Ω	510Ω	200Ω	—
0.47F	100Ω	200Ω	200Ω	200Ω	100Ω	100Ω
1.0F	100Ω	100Ω	100Ω	100Ω	100Ω	100Ω
1.4F	—	200Ω	—	—	—	—
1.5F	—	—	—	—	51Ω	—
2.2F	—	100Ω	—	—	—	—

g. Low Temperature Capacitance. For capacitance measurements at -55°C use test circuit resistor that is six (6) times the above table values. For example, R_c for 1.0F capacitor = 600Ω.

Figure 1. Capacitance

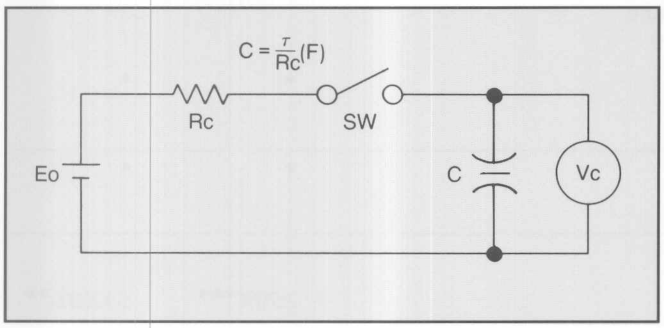
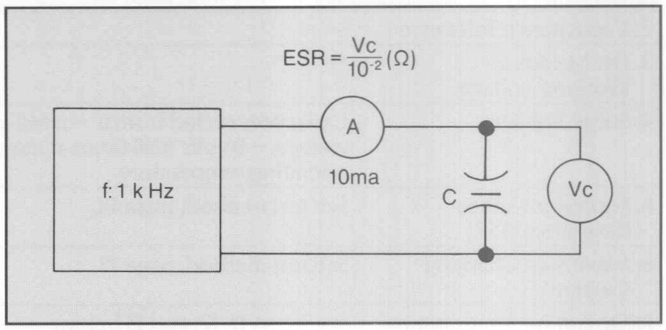


Figure 2. Equivalent Series Resistance (ESR)

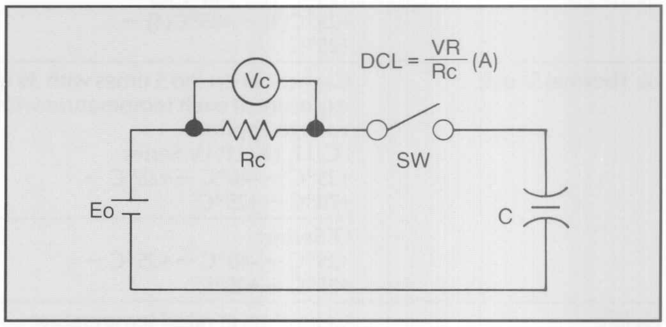


2. Equivalent Series Resistance (ESR)

ESR in ohms can be measured using the test circuit in Figure 2:

a. Test temperature and tolerance – Capacitor to be at +25°C ± 5°C.
b. Test frequency – 1,000 ± 100 Hz.
c. The magnitude of the AC voltage to be limited to 0.5 volt rms maximum.
d. A = Ampere meter (AC).
e. V_c = Volt meter (AC).
Note: Volt meter impedance to be significantly higher than that of the capacitor.

Figure 3. DC Leakage Current (Charging Current)



3. DC Leakage Current (Charging Current)

DC leakage current or charging current is measured using the test circuit and procedure in Figure 3:

a. Test temperature and tolerance – Capacitors to be at +25°C ± 5°C.
b. Initial capacitor voltage to be less than 0.05V.
c. V_c = Volt meter (DC).
d. E_o = 5.0 ± 0.1V for LC, LF, LK, LP, LT Series; 10.0 ± 0.1V for LV Series.
e. VR = Voltage drop by resistance R_c after 30 minutes on charge.
f. R_c = Charging resistor selected from the table below:

0.022F, 0.047F	1000Ω
0.1F to 0.47F	100Ω
1.0F to 2.2F	10Ω

Minimum Backup Time Capability

The following curves indicate the discharge times for Maxcap DLCs through constant resistance loads after charging for 24 hours at 5.0 volts.

Figures 4 and 5 show minimum backup time for a voltage range of from 5 to 2 volts, the typical data retention range for CMOS RAMs. The actual backup time will be longer than indicated because the current draw of CMOS RAMs over the data retention voltage is somewhat less than that of constant resistance loads even though the initial current is the same.

Figure 4. Minimum Backup Time Versus Initial Current for CMOS RAM Applications Using Maxcap DLC *LP and LF Series* from 5 to 2 Volts at 25°C

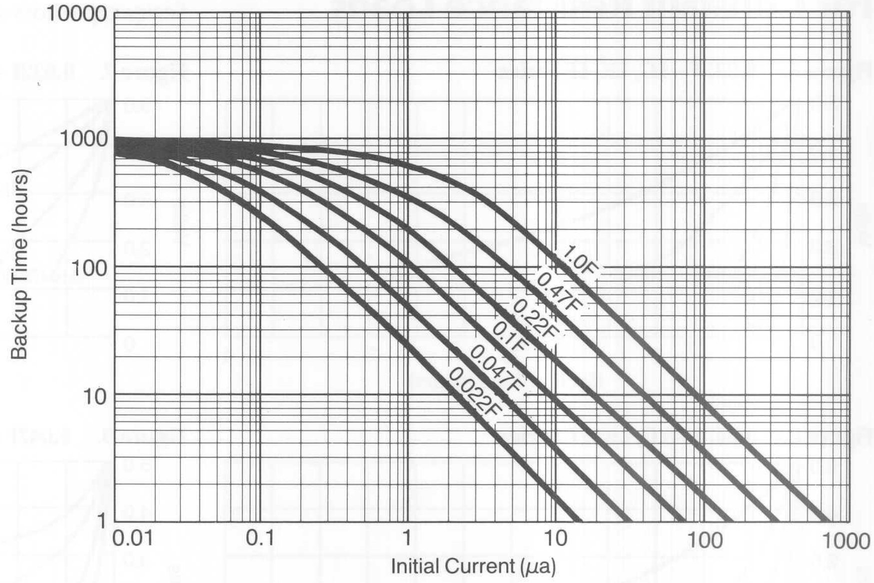
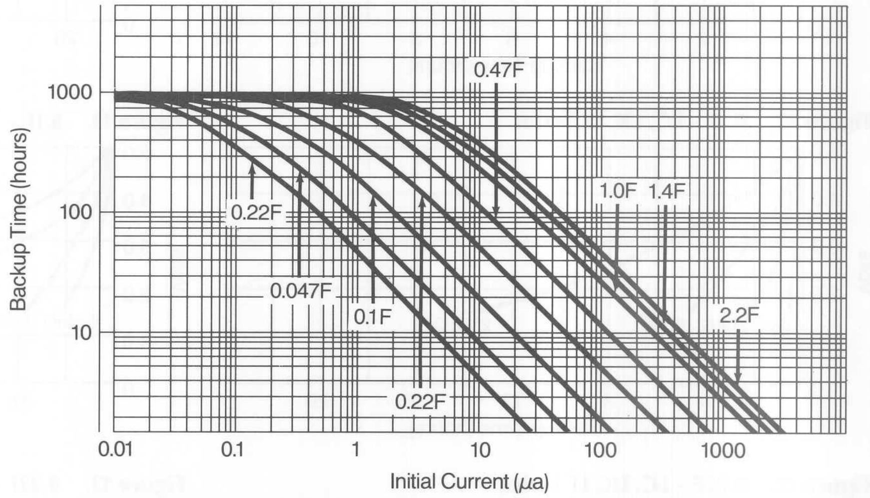


Figure 5. Minimum Backup Time Versus Initial Current for CMOS RAM Applications Using Maxcap DLC *LC, LK and LT Series* from 5 to 2 Volts at 25°C



Note: Figure 4 and 5 curves are based on discharge times of Maxcap DLCs through constant resistance loads. Initial current is the load current at 5.0 volts.

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Maxcap DLC Backup Times at 25°C For Constant Resistance Loads

Figures 6 through 29 show voltage versus backup time for a number of constant resistance loads for *LC, LK, LT and LV Series* capacitors after charging for 24 hours at 5.0 or 10 volts.

Figure 6. 0.022F – LC, LK, LT Series

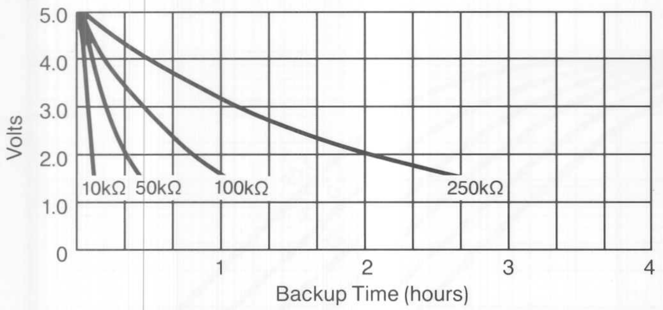


Figure 7. 0.022F – LC, LK, LT Series

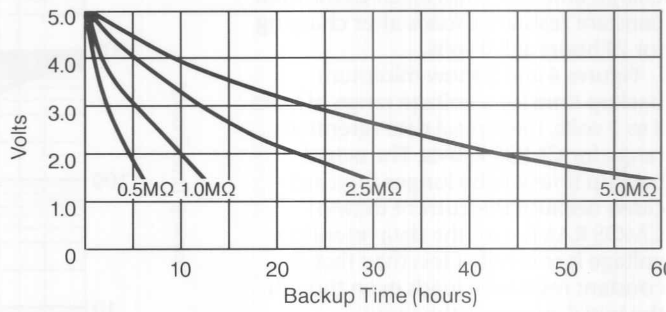


Figure 8. 0.047F – LC, LK, LT Series

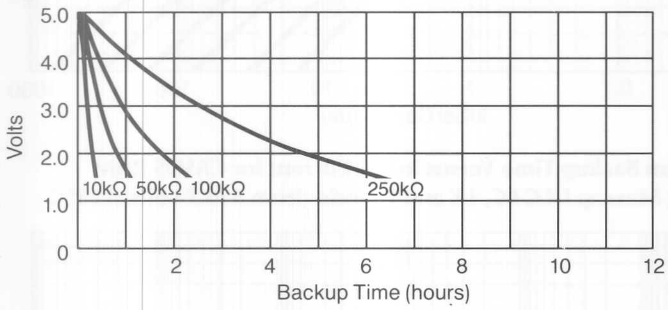


Figure 9. 0.047F – LC, LK, LT Series

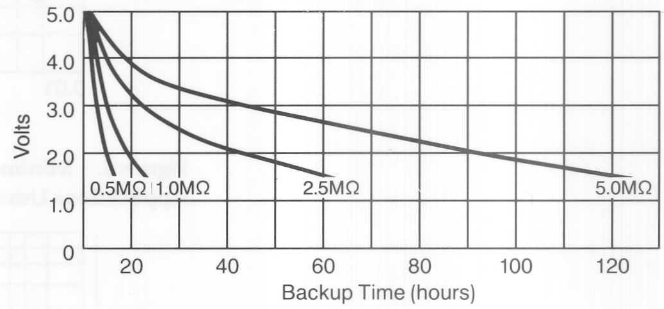


Figure 10. 0.1F – LC, LK, LT Series

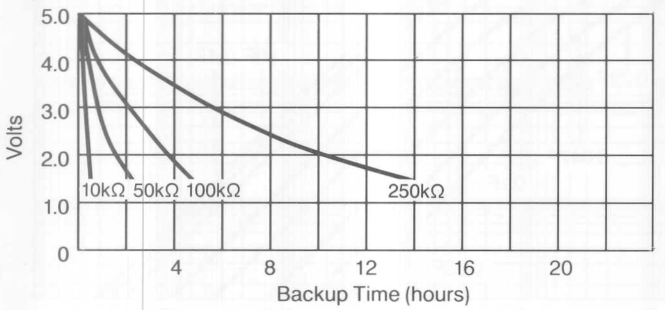


Figure 11. 0.1F – LC, LK, LT Series

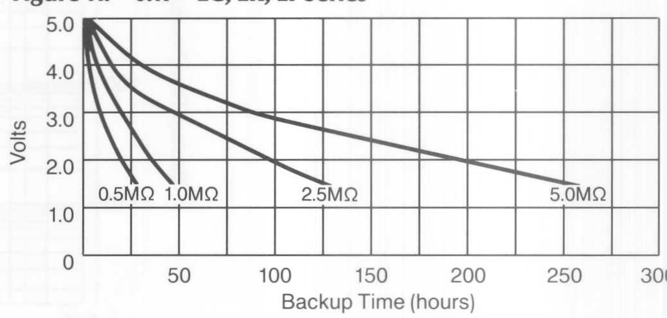


Figure 12. 0.22F – LC, LK, LT Series

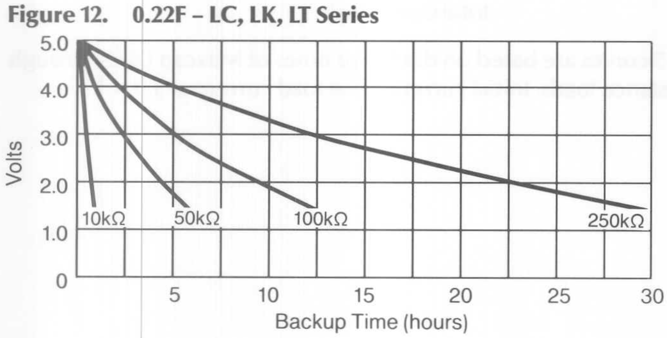


Figure 13. 0.22F – LC, LK, LT Series

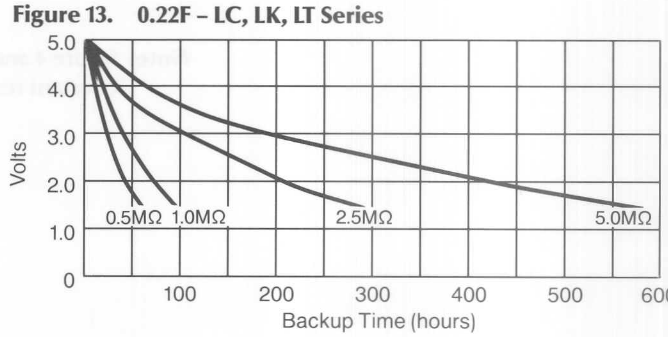


Figure 14. 0.47F – LC, LK, LT Series

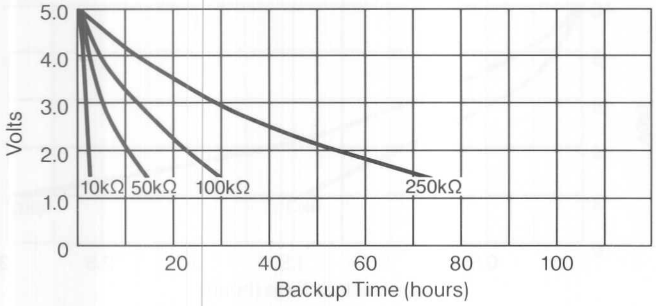


Figure 15. 0.47F – LC, LK, LT Series

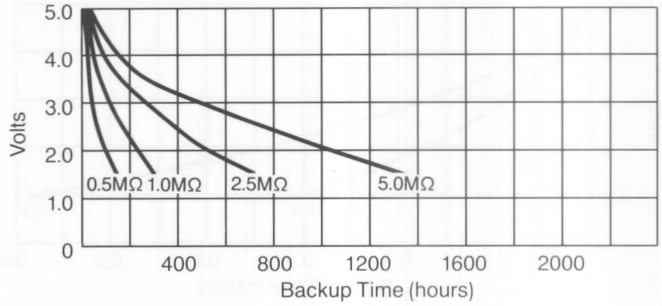


Figure 16. 1.0F – LC, LK, LT Series

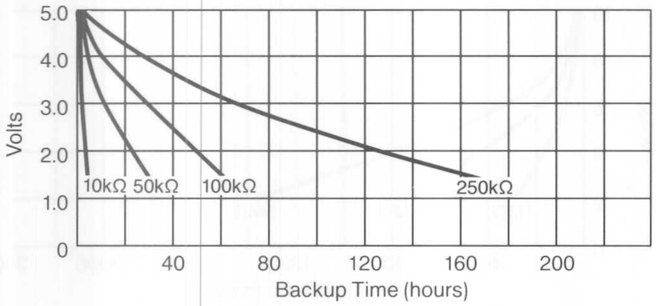


Figure 17. 1.0F – LC, LK, LT Series

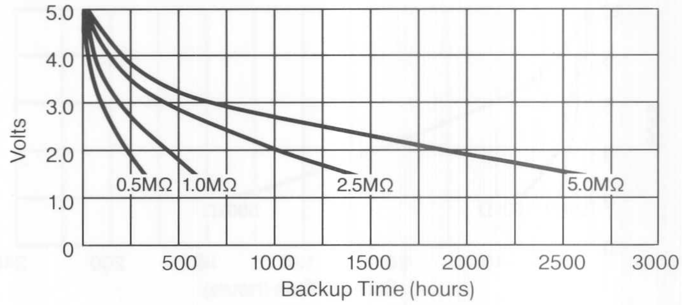


Figure 18. 1.4F – LC Series only

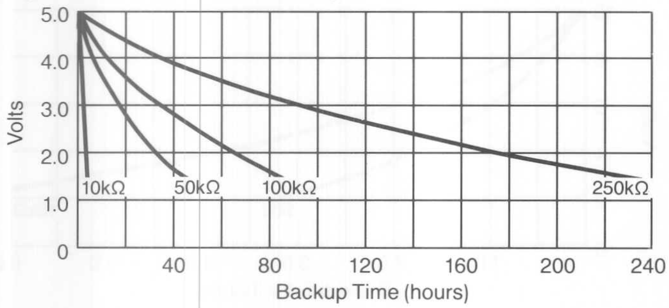


Figure 19. 1.4F – LC Series only

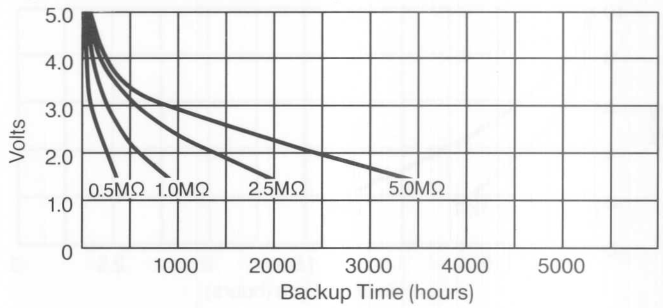


Figure 20. 2.2F – LC Series only

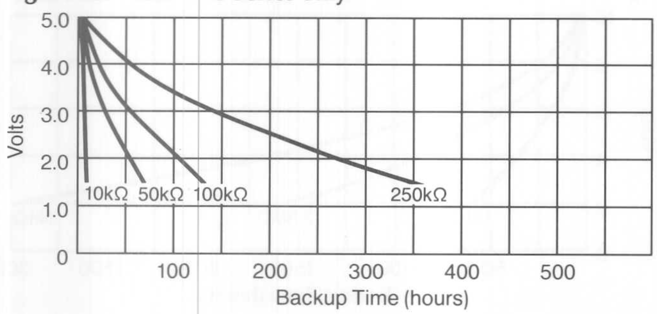
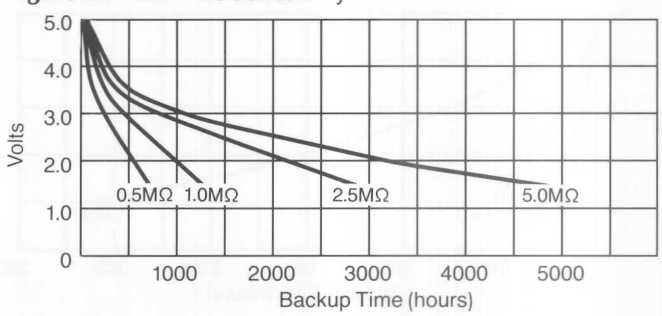


Figure 21. 2.2F – LC Series only



Maxcap DLC Backup Times at 25°C For Constant Resistance Loads (cont.)

Figure 22. 0.47F – LV Series

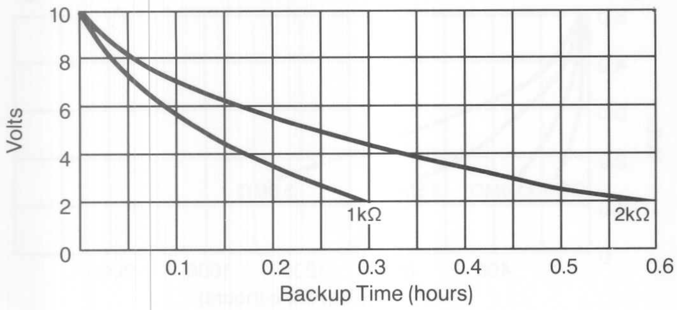


Figure 23. 0.47F – LV Series

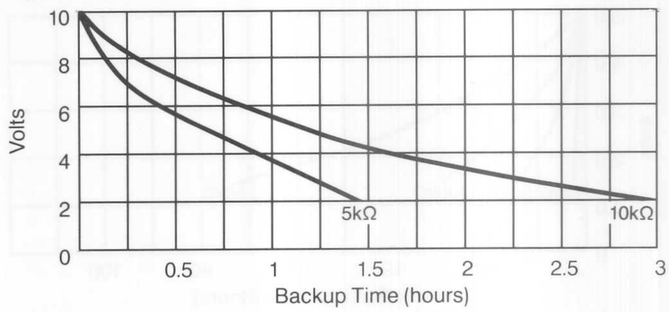


Figure 24. 0.47F – LV Series

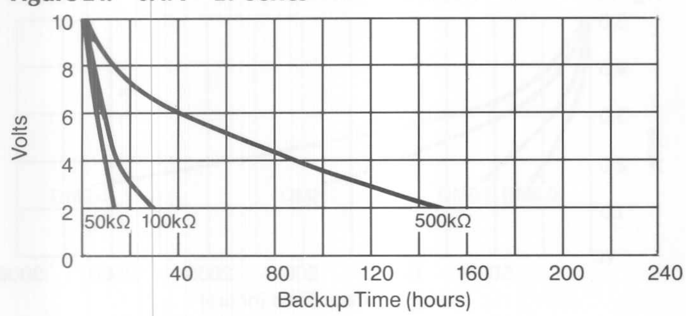


Figure 25. 0.47F – LV Series

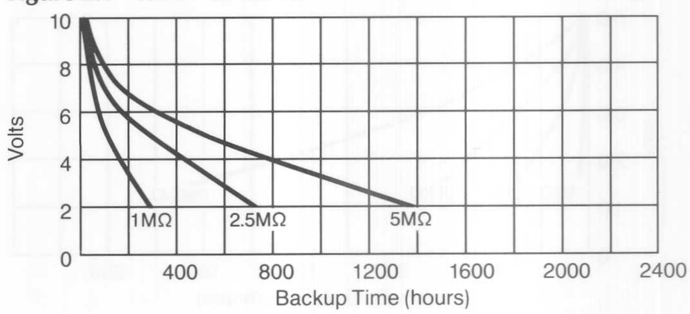


Figure 26. 1.0F – LV Series

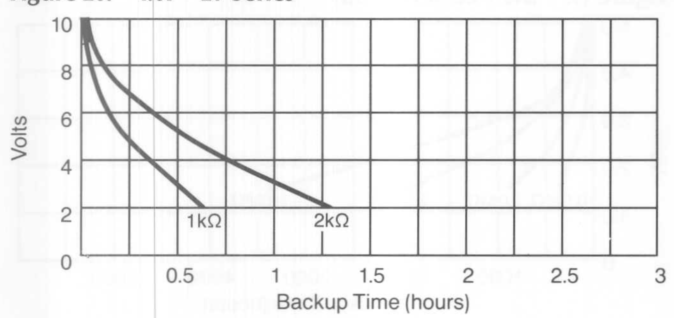


Figure 27. 1.0F – LV Series

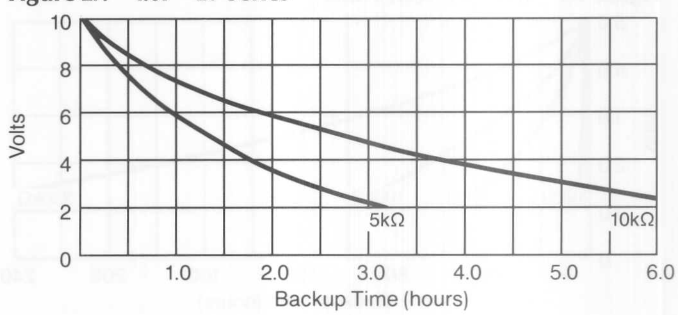


Figure 28. 1.0F – LV Series

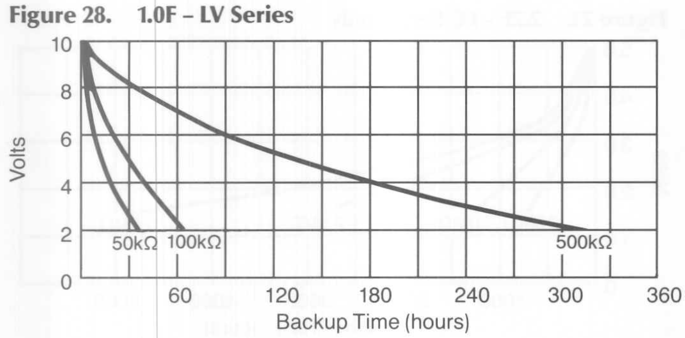
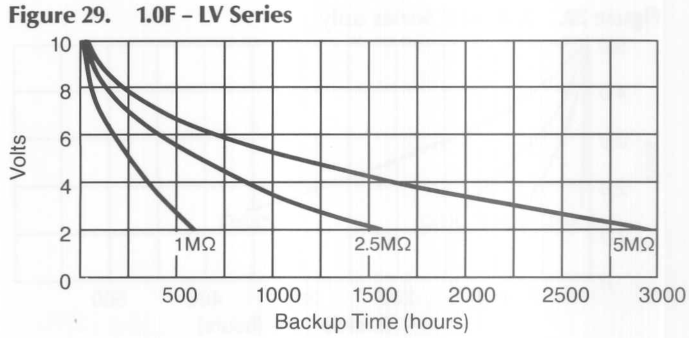


Figure 29. 1.0F – LV Series



Charging Characteristics

Maxcap DLCs can be charged to their working voltage in a matter of seconds. Typical charge time versus voltage and current curves are given in Figure 30.

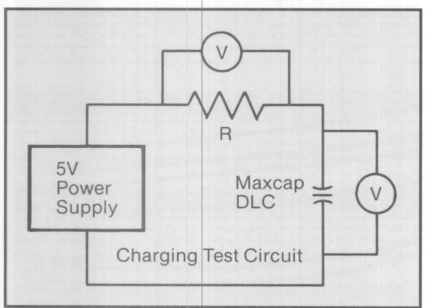
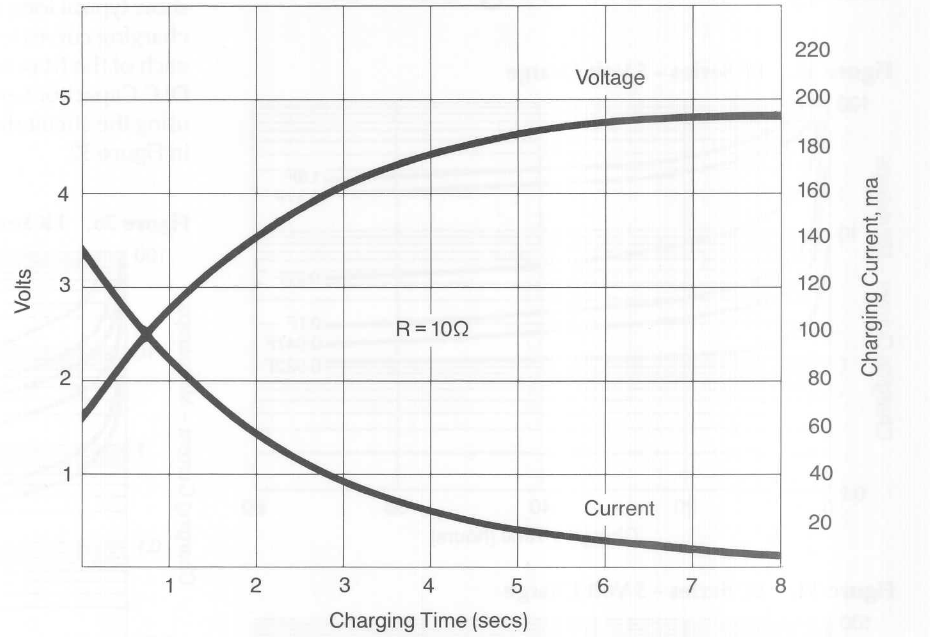


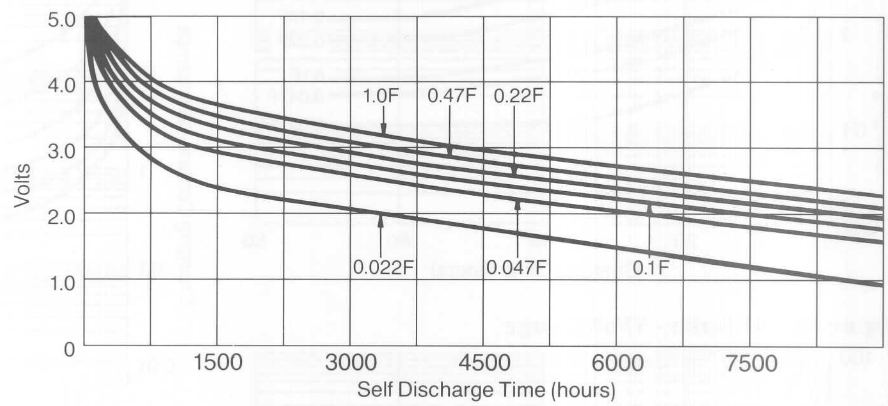
Figure 30. Charging Curves for Maxcap DLC LP055104A



Self Discharge Curves

Figure 31 shows self discharge curves (open circuit) for LC, LK and LT Series capacitors after charging for 24 hours at 5.0 volts.

Figure 31. Self Discharge Curves for LC, LK and LT Series



Long Term Charging Curves

Figures 33 through 38 show typical long term charging curves for each of the Maxcap DLC Capacitor Series using the circuit shown in Figure 32.

Figure 32.

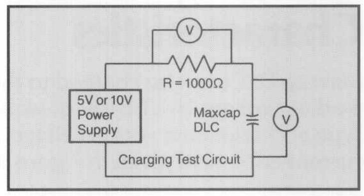


Figure 33. LP Series – 5 Volt Charge

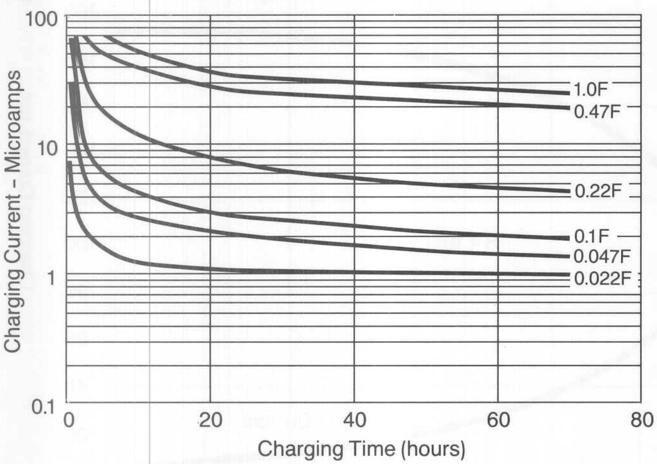


Figure 34. LC Series – 5 Volt Charge

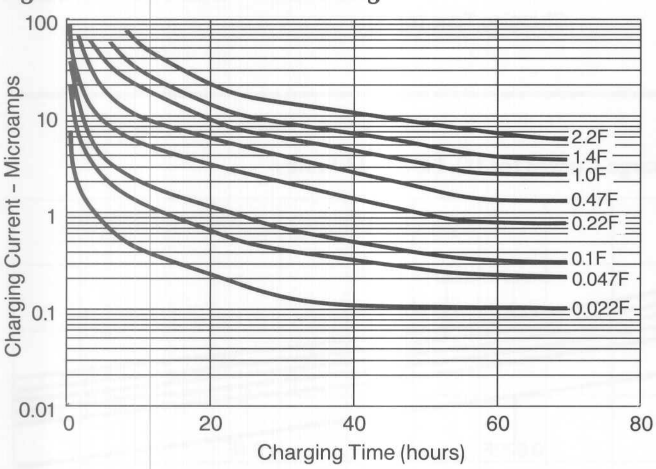


Figure 35. LF Series – 5 Volt Charge

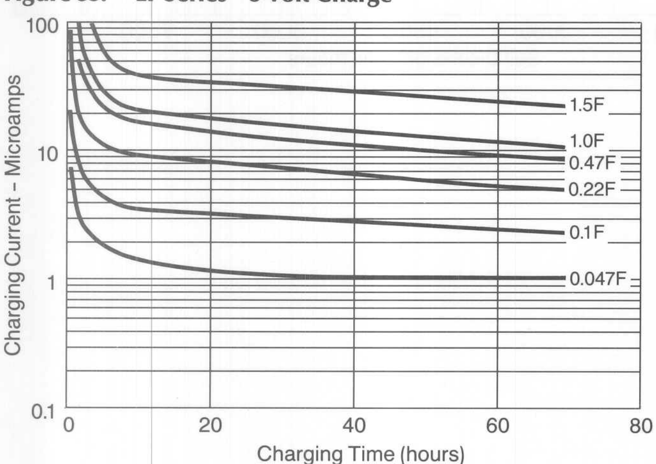


Figure 36. LK Series – 5 Volt Charge

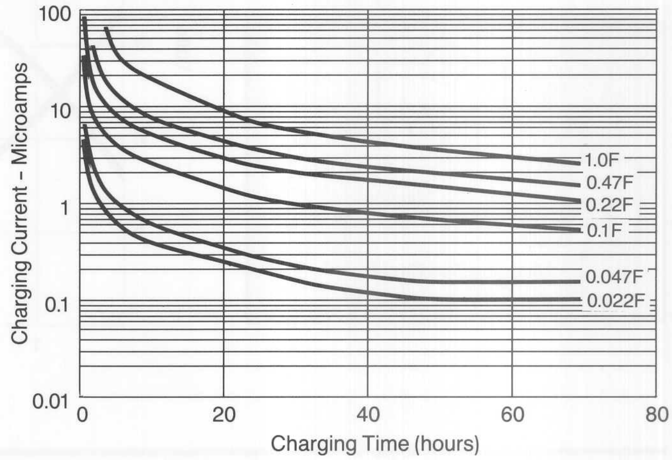


Figure 37. LT Series – 5 Volt Charge

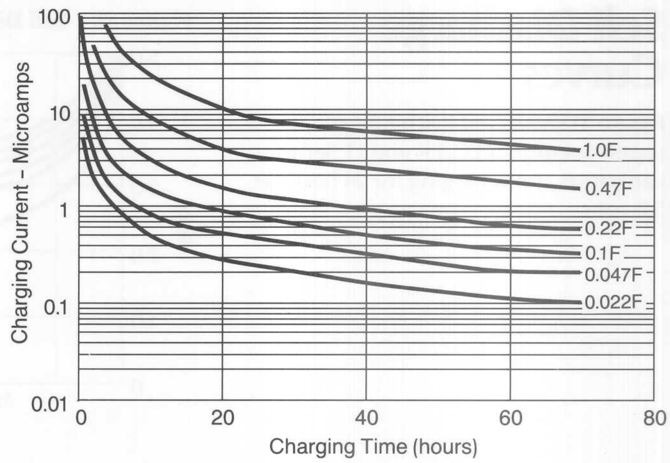
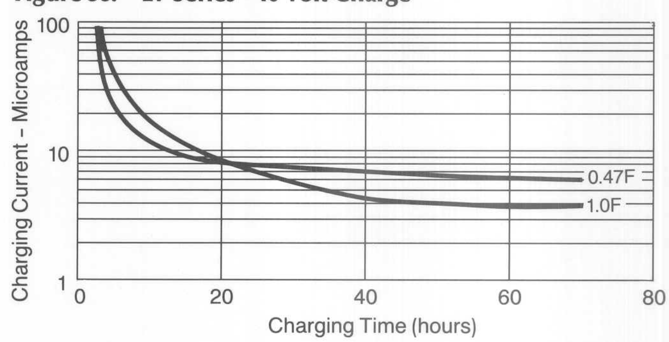


Figure 38. LV Series – 10 Volt Charge



Electrical Characteristics Versus Temperature

Figures 39 and 40 show typical changes in capacitance and ESR over the temperature range from -55 to +85°C. Note that the rated operating temperature for LP, LV, LC, LK and LF Series capacitors is -25 to +70°C; LT Series, -40 to +85°C.

Figure 39. Capacitance Versus Temperature – 1.0F Capacitors

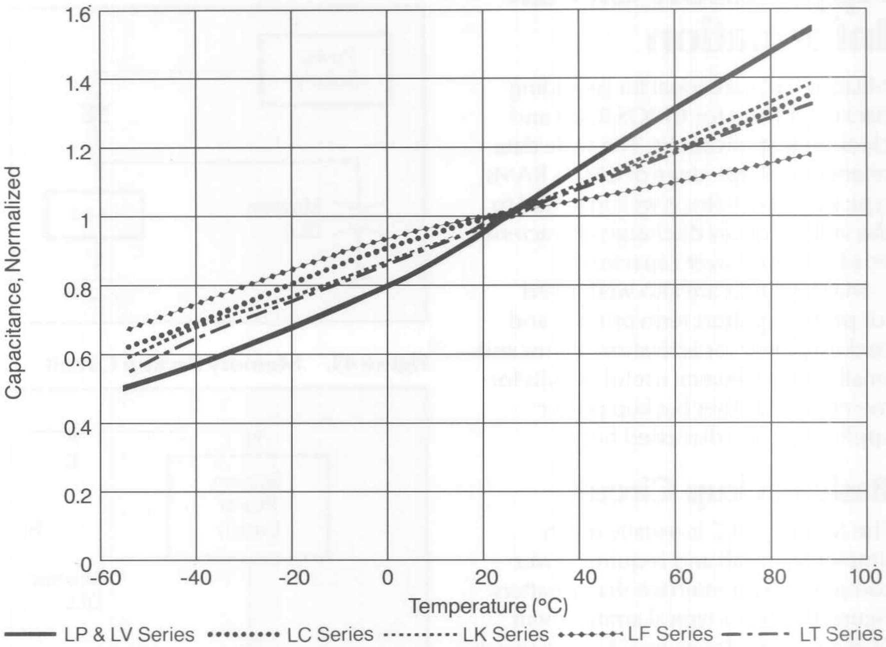
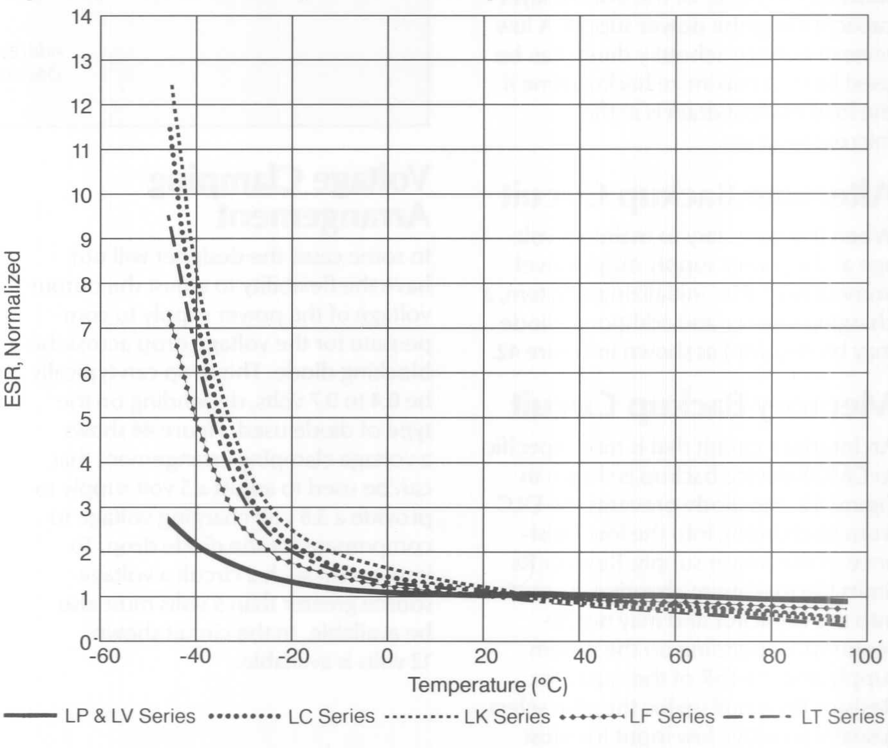


Figure 40. ESR Versus Temperature – 1.0F Capacitors



Application Circuit Information

Maxcap DLCs are ideal for providing backup current for CMOS RAM and clock chip applications. The wide data retention voltage range of CMOS RAMs, typically 5 to 2 volts, is well matched to the voltage decay discharge characteristic of a double layer capacitor.

Maxcap DLCs are also well suited for providing short term primary and backup power for activators, alarms and small motors. Several useful circuits for memory and other backup power applications are discussed below.

Basic Backup Circuit

The Maxcap DLC is usually much simpler to install and requires fewer components for interface than a battery. Figure 41 shows a typical arrangement of components for general backup power applications. The blocking diode prevents wasteful discharge of the double layer capacitor into the power supply. A low reverse leakage Schottky diode can be used here to maximize backup time if the load current drain is in the microamp range.

Alternate Backup Circuit

When it is necessary to maintain voltage at the power supply output level immediately after initializing a system, a charging resistor and additional diode may be required as shown in Figure 42.

Memory Backup Circuit

An interface circuit that is more specific to CMOS device backup is shown in Figure 43. The diode prevents the DLC from discharging into the low resistance of the power supply. Resistor Rs limits the maximum charging current into the capacitor and may not be required, depending on the system supply and the ESR of the capacitor. Resistor Rp is pull up for the chip select (usually an active low input for most static RAMs) that keeps the chip in the deselected or standby state while power is absent.

Figure 41. Basic Backup Circuit

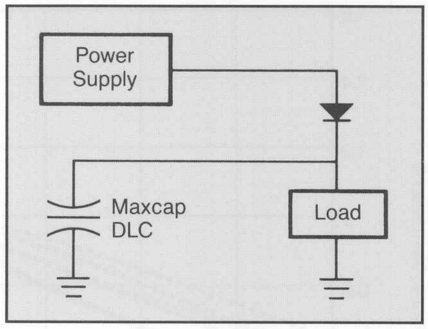


Figure 42. Alternate Backup Circuit

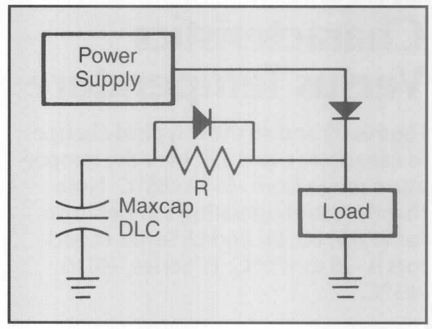
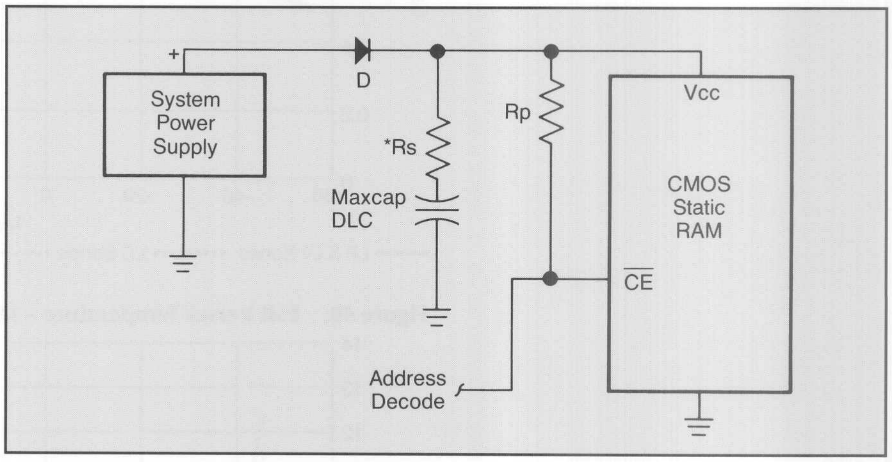


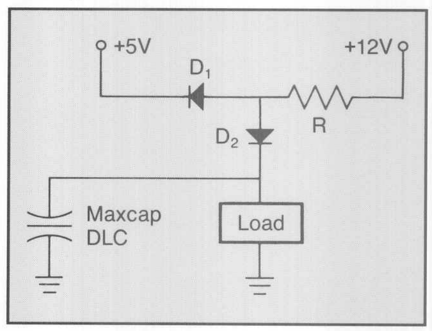
Figure 43. Memory Backup Circuit



Voltage Clamping Arrangement

In some cases the designer will not have the flexibility to adjust the output voltage of the power supply to compensate for the voltage drop across the blocking diode. This drop can typically be 0.4 to 0.7 volts, depending on the type of diode used. Figure 44 shows a voltage clamping arrangement that can be used to adjust a 5 volt supply to provide a 5.5 volt charging voltage to compensate for the diode drop. To implement such a circuit a voltage source greater than 5 volts must also be available. In the circuit shown, 12 volts is available.

Figure 44. Voltage Clamping Arrangement



Use Beyond Rated Voltages

Some systems may require backup power voltages in excess of the 5.5 and 11.0 volt maximum voltage rating of standard Maxcap double layer capacitors. Maxcap DLCs can be used in these applications by connecting devices in series to obtain the desired system backup voltage. Using the following guidelines will assure maximum performance and unlimited cycle life from Maxcap capacitors.

The main precaution to observe when using series-connected Maxcap DLCs is to make certain that the voltage across any individual device in the series string does not exceed the maximum voltage rating for extended periods of time. This can be accomplished by making sure the operating applied voltage does not exceed the sum of the individual Maxcap DLC maximum voltage ratings. Optimum operation can be achieved if the system applied voltage is distributed equally among all devices during charging and discharging of the capacitors.

The first step toward achieving a balanced condition is to use devices that are all of the same series and rated capacitance. In applications where only two devices are used and the duty cycle is relatively short, this alone may provide adequate balancing. However, in strings of more than two or under long on-charge times, there is increased risk of exceeding the capacitor rated voltage if no other measures are taken. During very long charge times, small variations in device capacitance and leakage current will be magnified and may result in relatively large imbalances. By examining the factors that cause unequal voltage distribution, the design engineer can implement effective means to minimize these effects.

The distribution of voltage across individual elements of a series string of DLCs is determined by the electrical characteristics of each device. The relevant properties are capacitance, leakage current and, to some extent, equivalent series resistance. The following example illustrates how these characteristics affect the charging of series-connected Maxcap DLCs. The following example shows what happens when the series connected Maxcap DLCs in Figure 45 are charged.

At the instant voltage is applied the voltage across C_1 is about 4.5 volts and across C_2 is 5.5 volts, in proportion to their ESR. This condition lasts only briefly. Since the capacitors are in series, each accumulates charge at the same rate. From the definition of capacitance, C = QV, the voltage across C_1 will increase faster by virtue of its lower capacitance at equal charge. At some point in the charge process, as the ultimate value of leakage current is approached, the higher steady-state leakage current of C_1 will cause its voltage to level off first. C_2's voltage will continue to increase, however, because of its lower leakage current. Eventually, C_1 and C_2 will reach the same steady-state leakage current. As shown in Figure 46, C_2's voltage will exceed that of C_1 at the same steady-state leakage current. The value of leakage current will be that current at which the sum of the capacitor voltages equals the applied ten volts.

This example illustrates that significant voltage differences can occur during the charging process. Several easy methods can be used to assure equalized charging.

To correct the situation occurring at the instant charging begins, a small resistance can be added in series with the capacitors to limit the initial value of inrush current, as shown in Figure 47. In many cases this resistor may be desirable anyway to limit the power supply current. The value of this resistor can be quite high, its upper limit being determined by the charging time required.

Of greater concern is the imbalance resulting from the difference in leakage current and capacitance as these effects are of longer duration and tend to build up over time. One corrective method is to simply add shunt resistors of equal value across each device to provide a voltage divider that forces equalization of voltage throughout the string. This reliable and inexpensive

Continued on page 22.

Figure 45 shows the series connection of two model LP055473A (0.047F) 5.5 volt capacitors having the following individual device properties:

Device	ESR (ohms)	Capacitance (F)	Leakage Current at 5 Volts (μa)
C_1	7.0	0.052	1.8
C_2	8.6	0.068	1.4

Figure 45. Series Connected Maxcap DLCs.

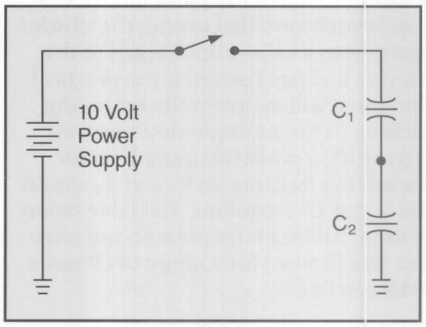


Figure 46. Series Connected Maxcap DLC Leakage Current Versus Voltage.

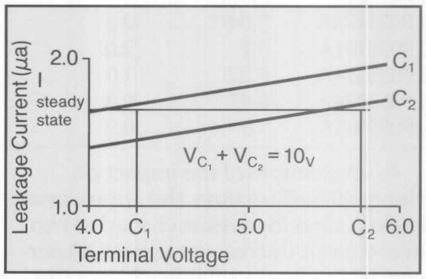
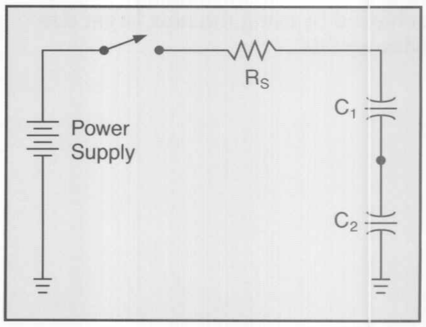


Figure 47. Series Resistor to Limit Charge Current.



Use Beyond Rated Voltages (Continued)

approach is shown in Figure 48. The only drawback to this solution is that the voltage divider resistors consume energy during the discharge portion of the cycle and thus can shorten the backup time available. As a practical matter, the resistors' value can usually be chosen such that their current draw is low relative to the load current. The resistors will then have no discernable effect on backup time.

The maximum value for these resistors is constrained by the leakage current range of the particular DLC. It has been found that setting the divider current to a value about equal to the device leakage current is the practical limit that will maintain the balancing action. In the example described in Figure 45, a practical upper limit for balancing resistors on R_1 and R_2 would be about 2.5 megohms. The table below shows maximum recommended resistor size (Rmax.) for a range of LP series Maxcap DLCs.

Model	Capacitance (F)	Rmax (Megohms)
LP055223A	0.022	5
LP055473A	0.047	2.5
LP055104A	0.1	2.0
LP055224A	0.22	1.0
LP055474A	0.47	0.3
LP055105A	1.0	0.2

As an example of the impact on Figure 45 backup time, the approximate backup time for a resistive load of two micro-amps decreases to about 50 percent of the time available without the resistors, with the probable lifetime greatly extended. If longer backup time is required, this situation can be achieved by using the next larger size Maxcap DLC.

Figure 48. Voltage Divider Using Shunt Resistors for Charge Balancing.

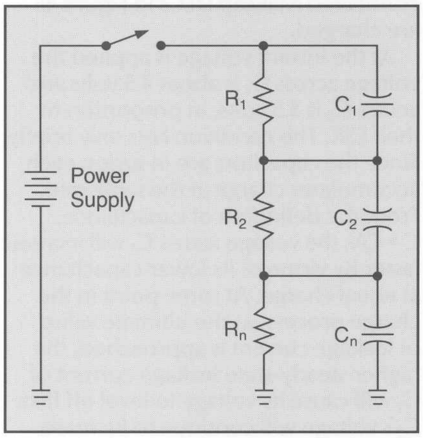
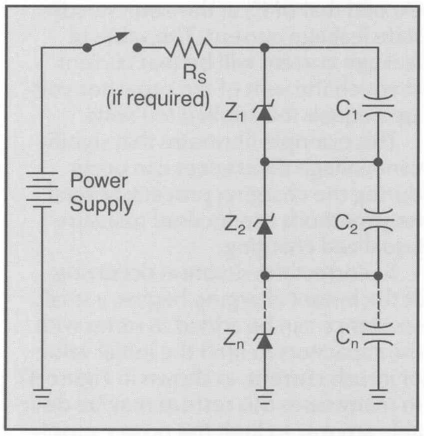


Figure 49. Voltage Divider Using Shunt Zener Diodes for Overvoltage Protection.



A lower value divider resistor will provide faster equalization, at the expense of recovery time and total dissipation. The lower limit should be determined by power dissipation and backup time limitations, and by charging time requirement.

Another method of providing overvoltage protection to the series of capacitors is to shunt each device with a zener diode of five to six volts, as in Figure 49. As the rising capacitor voltage exceeds the zener breakdown voltage, the diode begins to conduct and shunt charging current around the individual capacitor that is charging fastest. Additional charging current is thus directed to the capacitors that remain at a lower voltage, allowing them time to charge faster.

Unlike the method employing shunting resistors, this method has the advantage of not resulting in reduced backup time. The zener shunt method can be employed in cases where the resistor method would incur an intolerable backup time penalty but space limitations preclude an increase in Maxcap DLC size.

A precaution that should be observed is to make sure that the sum of the zener breakdown voltages in the string exceeds the total applied voltage. If it does not, a series resistor should be used to limit the zener current.

By using these simple techniques, Maxcap double layer capacitors can provide the benefits of high energy density and unlimited cycle life to applications for backup voltages beyond five volts.

Operating Principle

The Maxcap DLC capitalizes on the electric double layer principle first described by Helmholtz.* This model shows an array of charged particles and oriented dipoles that form at the interface of any two phases (solid/solid, solid/liquid, etc.). The interface exhibits a capacitive effect such that the application of an electric field results in an accumulation of electrostatic charges in a double layer.

The Maxcap DLC uses an electrode consisting of activated carbon into which an ionically conductive liquid electrolyte is absorbed. As shown in Figure 50, the electric double layer is created at the interface of the carbon and electrolyte.

In a classical plate capacitor, the capacitance (amount of charge that can be stored) is a function of plate area. The Maxcap DLC plate area corresponds to the area of the capacitive electric double layer. The extremely high surface area of the activated carbon electrode material, up to 1000 m^2/gram, makes the area of the double layer very large. This causes Maxcap DLCs to reach a commensurately high volumetric efficiency.

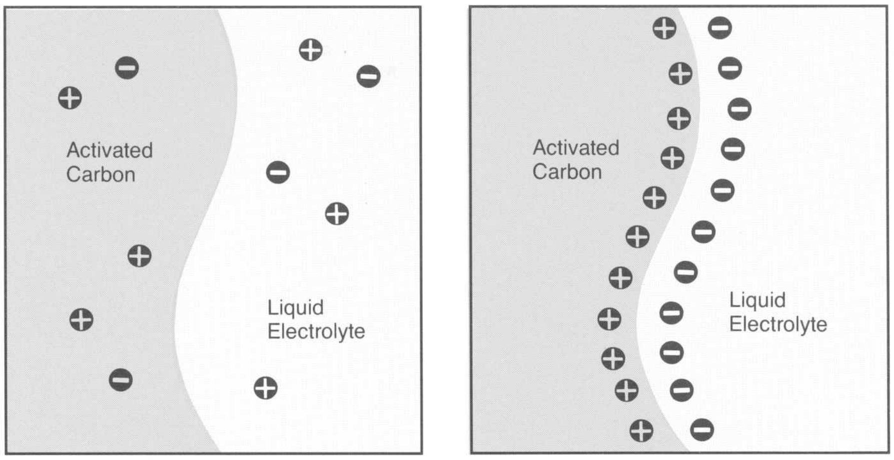
*H.L. von Helmholtz, Wied. Ann., 7, 33 (1879)

Figure 50. Electric Double Layer Principle

Double Layer – Formed with Two Phases in Contact

Capacitance – Arises when Potential is Applied

Electric Double Layer



With No Potential Difference Applied

With Potential Difference Applied

Construction

The construction of a Maxcap double layer capacitor is shown in Figure 51. Two identical electrolyte-moistened carbon electrodes face each other across an ionically conductive, porous separator. Electroconductive rubber endcaps provide the seal and electrical contact. The entire arrangement comprises one unit cell. Figure 53 illustrates the action of charge storage within a single unit cell.

The aqueous electrolyte used in the Maxcap DLC begins to break down at about 1.2 volts, the breakdown potential of water; therefore, capacitors with useful voltage ratings are constructed of a series-connected stack of unit cells inserted into a metal can. Six unit cells are stacked to build a Maxcap DLC rated at 5.5 volts. Twelve unit cells are stacked for a DLC rated at 11.0 volts. When charged to the rated voltage, each cell has a potential close to 0.9 volts. The difference between the breakdown and working voltages is a safety margin. The arrangement of a six-cell capacitor is shown in Figure 52.

Figure 51. Maxcap DLC Unit Cell Construction

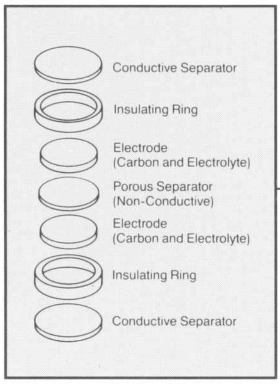


Figure 52. Maxcap Double Layer Capacitor Assembly

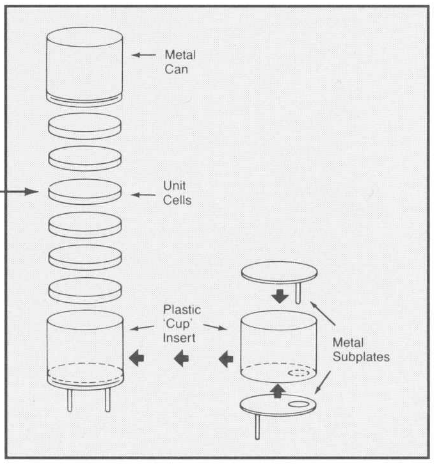


Figure 53. Maxcap DLC Unit Cell Operation